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**Review of control methods and severity of the Richardson's
ground squirrel problem in Saskatchewan**

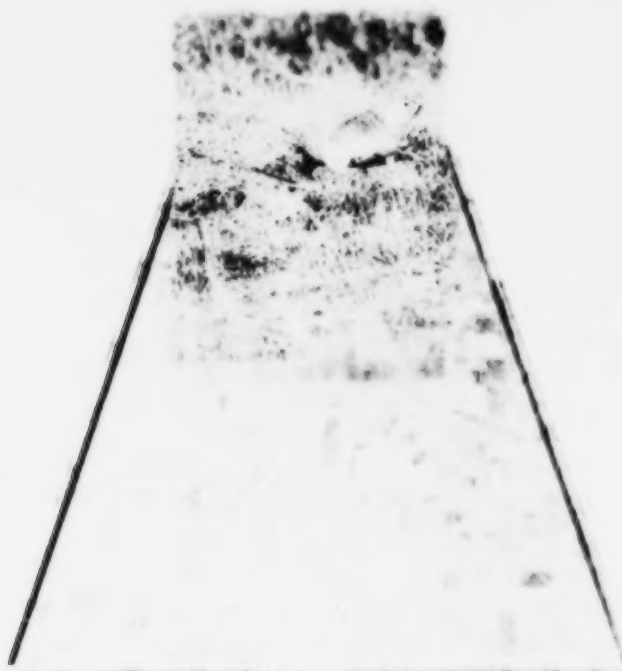
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REVIEW OF CONTROL METHODS AND SEVERITY OF
THE RICHARDSON'S GROUND SQUIRREL PROBLEM IN
SASKATCHEWAN



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and submitted to

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SUMMARY

Infestations of Richardson's ground squirrels (*Spermophilus richardsonii*) cause damage to annual crops, forage, and pasture in Western Canada on an annual basis. Diverse interested parties have different views on Richardson's ground squirrels and their control, largely because of different sources of information, some of them being anecdotal or qualitative in nature. This heterogeneity in the level of knowledge among interested parties often results in unjustified conclusions and false statements. The objectives of this study were to:

- 1) Review techniques that have been used in the past and those that are still in use for the control of Richardson's ground squirrels;
- 2) Review natural predators;
- 3) Estimate the distribution of the species in Saskatchewan;
- 4) Identify regions that may require more attention from a control point of view; and
- 5) Determine the producers' use of, and satisfaction with, current control methods.

The project consisted of two phases: 1) literature review and mail survey; and 2) field investigation. The literature review in scientific journals, books, symposia, and technical reports treating control methods for ground squirrels and other fossorial rodents resulted in a synthesis of information for chemical, mechanical, cultural and natural methods. A total of 165 questionnaires were mailed in September 2008 to a selected number of Saskatchewan rural municipalities within each major soil zone of the province. Field investigations of the Richardson's ground squirrels' distribution and abundance were conducted in May-June 2008 in 12 rural municipalities selected in 4 soil zones. Grass height was recorded at each study plot, and classified as short (< 15 cm) or tall (≥ 15 cm).

While no toxicant is without defaults, strychnine, anticoagulants, and gases are currently available and, if used properly, can control $>70\%$ of ground squirrel populations. However, their application in the field should be done in such a manner to not impact on non-target species, predators and scavengers. A long-term, effective management of Richardson's ground squirrel populations should integrate chemical, mechanical, cultural and natural control methods.

The Richardson's ground squirrel problem has been reported in most agricultural regions of the province. At first sight, it appears that there is a larger ground squirrel infestation in the Brown soil zone. However, some of the study plots of the Black and Gray soil zones had very high densities of ground squirrels. Various factors such as vegetation height and farming practices likely play a role on the species distribution and densities. More work will be required on the ecology of Richardson's ground squirrels to understand factors that impact on their distribution and abundance.

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1.0 INTRODUCTION

Infestations of Richardson's ground squirrels (*Spermophilus richardsonii*) cause damage to annual crops, forage, and pasture in Western Canada on an annual basis (Hartley and Proulx 2008). Also, during the last 15 years, the Richardson's ground squirrel problem has been the subject of general reviews (Proulx and Feldstein 1994, Bernard et al. 2004), workshops on burrowing rodents held in Edmonton in 1997 and in Saskatoon in 2002, and research (Bourne et al. 2002, Proulx and Walsh 2007, Proulx et al. 2009a, and others). Diverse interested parties have different views on Richardson's ground squirrels (Dakin 2003) and their control (Branswell 1988, Paul and Paul 1997, Michener 1999), largely because of different sources of information, some of them being anecdotal or qualitative in nature. This heterogeneity in the level of knowledge among interested parties often results in unjustified conclusions and false statements.

The severity of Richardson's ground squirrel infestations across Saskatchewan is also a subject of controversy. According to the Saskatchewan Agriculture and Food's (2001), Richardson's ground squirrels are more likely to be reported in the Brown and Black soil zones, and less likely in Dark Brown and Gray soil zones. On the other hand, the Richardson's ground squirrel distribution may not be related to soil types but rather to vegetation height. Indeed, ground squirrels establish their burrow systems in fields with shorter vegetation; they prefer sites with good visibility and short vegetation (Yensen and Sherman 2003).

The objectives of this study were to:

1. Review techniques that have been used in the past and those that are still in use for the control of Richardson's ground squirrels;
2. Review natural predators;
3. Estimate the distribution of the species in Saskatchewan;
4. Identify regions that may require more attention from a control point of view; and
5. Determine the producers' use of, and satisfaction with, current control methods.

2.0 METHODS

The project consisted of two phases: 1) literature review and mail survey; and 2) field investigations.

2.1 LITERATURE REVIEW AND MAIL SURVEYS

This phase consisted of an extensive review of scientific journals, books, symposia, and technical reports treating ground squirrel control methods. Although the search focused on Richardson's ground squirrel populations inhabiting western Canada, pertinent papers on this species in western United States, on other species of ground squirrels, and on fossorial rodents in general were considered to improve our understanding of control methods. The following categories of control methods were reviewed: 1) chemical, 2) mechanical 3) cultural, and 4) natural.

A total of 165 questionnaires were mailed in September 2008 (with a covering letter explaining the purpose of the project, and an addressed postage-paid envelope for their return) to a selected number of Saskatchewan rural municipalities within each major soil zone of the province (Table 1)¹. The questionnaires aimed to determine the producers' perception of the severity of the problem in their area, and identify which products appeared to have been the most efficient during control campaigns. An attempt was made to gather quantitative information on the efficacy of control methods.

Table 1. Distribution of questionnaires to rural municipalities of Saskatchewan.

<i>Soil Zone</i>	<i>Rural municipalities</i>	<i>Number of questionnaires mailed</i>
Brown	Stonehenge	15
	Landing	15
	Kindersley	15
Total		45
Dark brown	Lomond	23
	Harris	22
Total		45
Black	Orkney	30
Total		
Gray	Preeceville	12
	Bjorkdale	33
Total		45
All zones		165

2.2 FIELD INVESTIGATIONS

Field investigations of the Richardson's ground squirrels' distribution and abundance were conducted from 17 May to 15 June, 2008. Twelve rural municipalities were selected for field investigations in 4 soil zones (Figure 1): 3 in Brown (rural municipalities nos. 73, 167, and 290), 3 in Dark Brown (nos. 67, 111, 316), 3 in Black (nos. 224, 405, 470), and 3 in Gray (nos. 334, 426, 588). Because Richardson's ground squirrels infestations are more severe in forage fields and pastures (Saskatchewan Agriculture and Food's 2001), we selected 3 hayfields or pastures in each municipality after contacting the local administration. In total, 36 study plots were inventoried in 12 fields. Grass height was recorded at each study plot, and classified as short (< 15 cm) or tall ($\geq$ 15 cm) (Figure 2).

Visual counts: A 70 m x 70 m (0.49 ha) study plot was established at the southwest corner of each selected hayfield or pasture. Ground squirrel numbers in each of these sites were recorded using binoculars in three 3-min-long scans separated by a 5-min interval (Bourne et al. 2002, Johnson-Nistler et al. 2005). Surveys were completed by mid-morning. In an attempt to minimize the number of variables affecting counts, the same observer conducted all the scans, approximately 25 m from the border of study plots, under similar environmental conditions from day to day to avoid a variation in squirrel activity associated with weather (Bourne et al. 2002). For each field, the highest number of Richardson's ground squirrels counted in 3 scans was

¹ We contacted several municipalities for a list of producers' names and addresses. Unfortunately, several of them refused to participate in the survey due privacy concerns.

retained (Fagerstone 1984). For each rural municipality, the mean of the 3 highest visual counts for the 3 investigated fields was used in a comparison of ground squirrel densities.

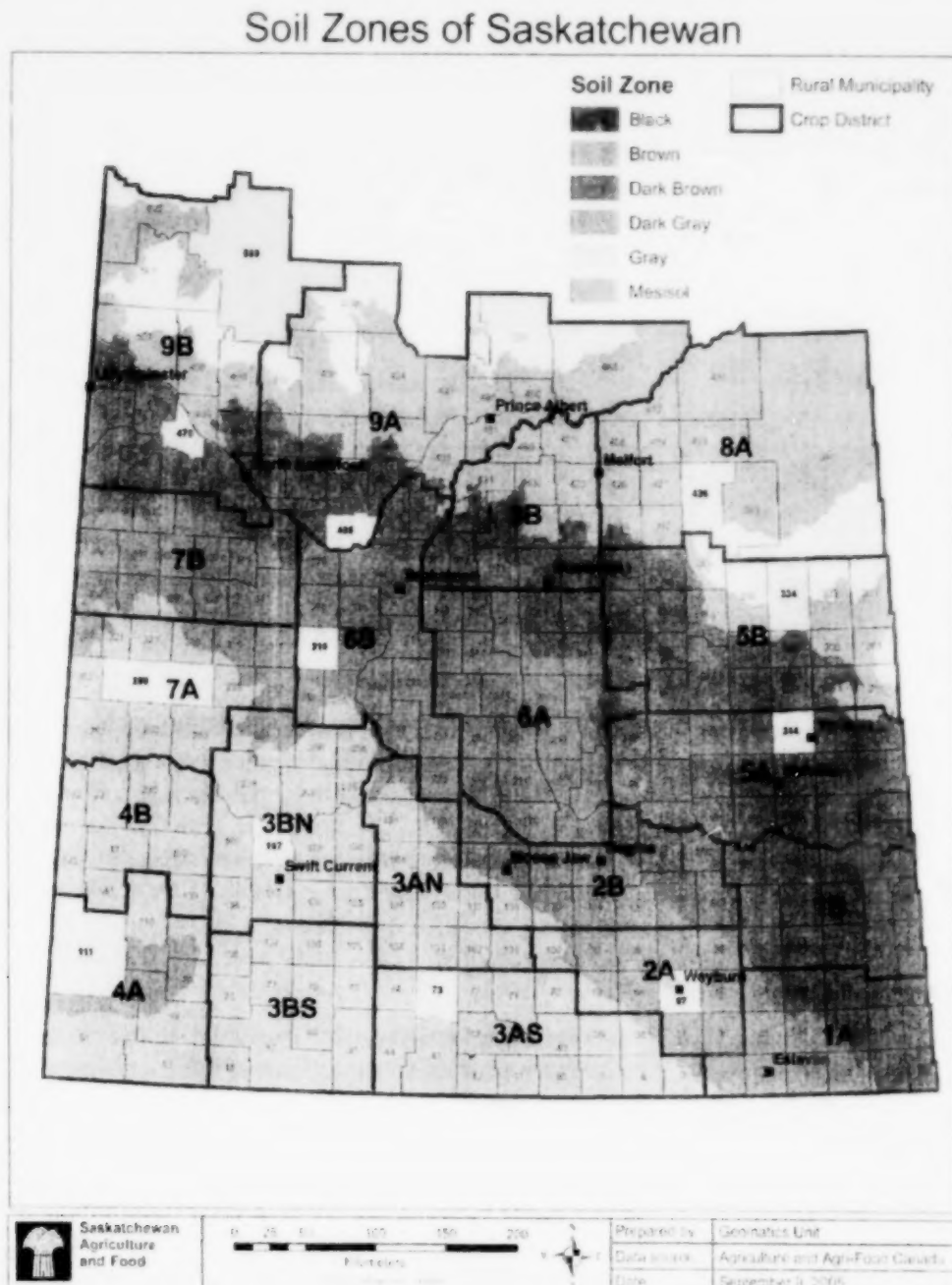


Figure 1. Rural municipalities (highlighted in yellow) where counts of Richardson's ground squirrels and burrow holes were investigated, May-June 2008.

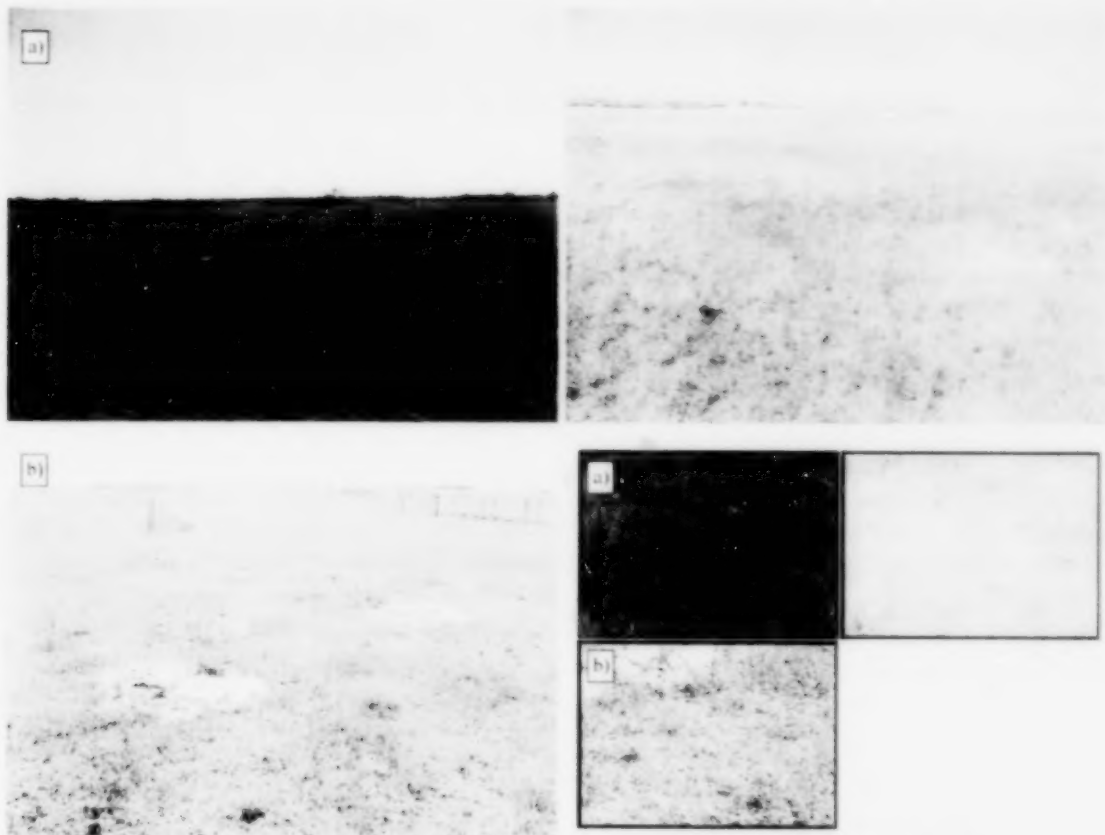


Figure 2. Examples of fields with a) >15-cm-high, and b) <15-cm-high vegetation.

Burrow hole counts: Richardson's ground squirrel burrow holes located within 30 cm of either side of the rope used to establish each of the 70-m-long sides of the 0.49 ha study plots were counted. Therefore, for each study plot, burrow holes were tallied along a 280-m-long transect.

2.3 DATA ANALYSES

An analysis of variance was used to compare average percentages of infestation by Richardson's ground squirrels in pastures, hayfields and crops calculated from mail survey responses. Visual counts and number of holes/study plot were averaged for each study plot. Analyses of variance followed by a Tukey test were used to compare mean values between regions (Zar 1999). Student-*t* tests were used to compare the mean number of animals observed and the mean number of burrow holes counted in fields with tall vegetation vs. those with short vegetation (Dixon and Massey 1969). Probability values $P \leq 0.05$ were considered significantly different.

3.0 LITERATURE REVIEW

3.1 CHEMICAL CONTROL

3.1.1 Toxicants

3.1.1.1 Toxicants no longer on the market

Arsenic oxide and related compounds

At one time, arsenic oxide and closely related compounds were widely used rodenticides. Arsenic is toxic by ingestion, inhalation and skin absorption. It causes respiratory distress leading to acute pulmonary edema (Canadian Pharmaceutical Association 1989). Owing to the general restrictions imposed by most countries on the sale of arsenic compounds, their use has sharply decreased (Gratz 1973), and they are unacceptable for the control of ground squirrels.

Sodium monofluoroacetate (Compound 1080)

Compound 1080 is the synthetic sodium salt of fluoroacetic acid (fluoroacetate) which was first identified in nature as the main component in the South African poisonous plant gifblaar (*Dichapetalum cymosum*) by Marais (1944). It is a highly effective rodenticide developed by the US Fish & Wildlife Service through the screening of over 1000 potentially rodenticidal compounds (Kalmbach 1945). This toxicant interferes with the metabolism of citrate in the Krebs cycle which affects all body cells. It causes respiratory depression. Death is due to cardiac toxicity (Canadian Pharmaceutical Association 1989). It causes death rapidly in rodents, often within 1 hour, after the consumption of very small quantities. Compound 1080 is also extremely poisonous to human beings (Brookes 1975). No specific antidote is available (Gratz 1973).

Rodents are known to develop "bait shyness" after ingesting sublethal rations of this poison (Barnett and Spencer 1949). Wood (1965) found that Compound 1080 was about 10% more effective than strychnine in controlling various rats and mice. O'Brien (1978) also found that cabbage-treated baits reduced ground squirrels activity by 95%. In 1964, the Leopold Committee recommended that Compound 1080 be banned as a rodenticide because of secondary hazards (Hood 1972). Hegdal et al. (1986) also reported secondary toxicity of Compound 1080 in various non-target birds and mammals.

3.1.1.2 Current toxicants

The following toxicants are currently used for the control of ground squirrels and other fossorial mammals:

- Anticoagulants
- Calcipherol & Cholecalciferol
- Foam
- Gases
- Strychnine
- Zinc Phosphide

Anticoagulants

Anticoagulants have been developed in the early 1950's (Meehan 1984). All the anticoagulants have one of two possible chemical types:

- Hydroxycoumarins
 - Old generation: Coumachlor, Coumafuryl, Coumatetradyl, Warfarin
 - New (second) generation: Brodifacoum, Bromadiolone, Difenacoum, Flocoumafen
- Indane-diones: Chlorophacinone, Diphacinone, Pindone.

Although different in their chemical structure, their physiological effect on animals is the same: they render blood incapable of coagulation, causing death by haemorrhage (Meehan 1984). Anticoagulants work by blocking the epoxide reductase enzyme inhibiting recycling of vitamin K (Silverman 1980). Without sufficient incoming vitamin K, the ability to produce clotting factors is inhibited and haemorrhaging begins (Halder and Buckle 1992). Plants rich in vitamin K counteract the effect of anticoagulants on ground squirrels (Arjo and Nolte 2004). Proulx and Walsh (2007) and Proulx et al. (2009a) showed that, in fields with at least 40% alfalfa, chlorophacinone controlled <65% of ground squirrels. In contrast, in the absence of alfalfa, control levels were > 70%. The main advantage of anticoagulants is that they do not induce bait or poison shyness. They are slow acting and when symptoms develop, animals have already consumed a lethal dose (Nachman and Hartley 1975). Their toxicity to rodents varies with species, and sex and age classes (Bull 1976, Grand 1976, Marsh et al. 1977, Dubock and Kaikeinen 1978, Meehan 1984, Lund 1988). Multiple feedings of the anticoagulants over a period of a week in the case of the ground squirrels are necessary to produce a high percentage of mortality (Marsh 1994). This therefore increases the cost of rodent control in both material and labour (Marsh 1986). Ali et al. (1994) recommended that anticoagulants be used before green-up of spring vegetation. However, Askam (1985) and Proulx et al. (2009a) reported high performance levels in presence of green vegetation other than alfalfa.

Public concerns relative to the use of anticoagulants include non-target (primary poisoning through direct ingestion) and secondary poisoning (consumption of poisoned animals), and a non-humane death where the animals bleed internally for several days (Paul and Paul 2007). Clinical signs of anticoagulant poisoning include ataxia, diarrhoea, haemorrhage, weakness (Meehan 1985). Sainsbury et al. (1995) estimate that animals sustain severe pain and distress for several hours to a few days. Many scavengers and predators feed on Richardson's ground squirrels, and although some of them may eviscerate them before eating them (Marsh et al. 1987, Schmutz et al. 1989), they are all at risk of secondary poisoning. As predators preferentially select for prey moving slowly or abnormally, they will focus on ground squirrels displaying a pre-lethal anticoagulant-toxicosis-induced behaviour that increases exposure and vulnerability to predation (Wood and Phillipson 1977, Brakes and Smith 2005). While it is difficult to find carcasses and ascertain cause of death, there is no doubt that predators that feed on moribund, anticoagulant-poisoned ground squirrels will also develop symptoms of toxicosis and consume lethal doses.

Proulx et al. (2009a) working with chlorophacinone reported the loss of small mammals and songbirds that fed on baits, and the secondary poisoning of badgers that fed on moribund ground squirrels. Poisoned weasels, red foxes (*Vulpes vulpes*), kit foxes (*Vulpes macrotis*), cats (*Felis*

catus), raccoons (*Procyon lotor*), crows (*Corvus* spp.), owls, red-tailed hawks (*Buteo jamaicensis*) and bald eagles (*Haliaeetus leucocephalus*) have been found in areas where rodents are controlled with anticoagulants (brodifacoum, bromadiolone, chlorophacinone, diphacinone) (Alterio 1996, Berny et al. 1997, McDonald et al. 1998, Hosea 2000, Stone et al. 1999, Kupper et al. 2006). Acute LD₅₀ indicate that brodifacoum has the highest toxicity of the anticoagulants for both birds and mammals (Hosea 2000). In birds, the second most toxic compound is bromadiolone. Diphacinone appears to have a higher toxicity than bromadiolone for canids and felids, but it ranks below bromadiolone for other mammals (Anonymous 2000, Stone et al. 1999). Chlorophacinone appears to be the least toxic of the compounds for mammals while diphacinone is the least toxic compound in birds. In July 1999, based on the significant numbers of exposed non-target wildlife, the California Department of Fish and Game requested that the California Department of Pesticide Regulation place all products containing the active ingredient brodifacoum (toxic potency about 200-fold that of warfarin and a half-life as much as 60 times longer; James et al. 1992) into re-evaluation. Also, the United States Environmental Protection Agency (EPA) is considering banning some second-generation anticoagulant poisons used in the control of rats (Palmer 2007). Recent work in countries where anticoagulants have been used in large quantities in agricultural regions indicated that predators and scavengers of poisoned rodents are at most risk of secondary poisoning, and reduced local populations of non-target small mammals may limit the food supply of some specialist predators. (Brakes and Smith 2005).

Interestingly, Eisemann and Petersen (2002) reported accidental exposure of humans to anticoagulants accounted for 82 to 89% of all rodenticide incidents.

Bromadiolone

O'Brien (1979) controlled < 70% of the animals with bromadiolone. Askam (1985) suggested that the combination of too much precipitation and O'Brien's (1979) inability to perform multiple treatments may have resulted in a lack of efficiency. On the basis of active burrow hole counts, Askam (1985) concluded that bromadiolone has the potential to control $\geq 70\%$ of ground squirrels. However, this evaluation technique is unreliable for anticoagulants (Proulx and Walsh 2007, Proulx et al. 2009a).

Chlorophacinone

O'Brien (1979) controlled < 70% of the animals with chlorophacinone, but the tests may have not been adequate (Askam 1985). Tests conducted in southern Saskatchewan demonstrated that chlorophacinone, when applied in burrow openings, can control > 70% of ground squirrel inhabiting grasslands (Proulx and Walsh 2007, Proulx et al. 2009a). In alfalfa fields, however, the ability of chlorophacinone to control ground squirrels is < 70% (Table 2). Interestingly, Johnson-Nistler et al. (2005) concluded that chlorophacinone controlled, on average, 84% of Richardson's ground squirrels in alfalfa or alfalfa-grass mixtures (the percentage of alfalfa is unknown) on the basis of visual counts, without taking into consideration natural mortality. Yet, Proulx and Walsh (2007) and Proulx et al. (2009a) showed that visual counts were an unreliable technique to assess the efficacy of anticoagulants. Askam (1985) used burrow hole counts to assess efficacy levels. Proulx and Walsh (2007) and Proulx et al. (2009a) showed that this technique was also unreliable to assess the efficacy of anticoagulants. Proulx et al. (2009a) showed that anticoagulants, either served in small amounts in burrow openings or in large quantities in bait stations, are effective in native grasslands in spring. However, a disadvantage

of bait stations is that animals continue to feed on large quantities of poison for several days after ingesting a lethal dose, thus resulting in excess consumption of toxicant.

Diphacinone

No-choice feeding trials, and free-choice tests with laboratory chow, suggested that diphacinone-treated baits could kill ground squirrels within 4-22 days (Marsh and Howard 1975a, 1976). In field trials, diphacinone was found to be effective to control California ground squirrels (Table 2). It is mixed with a blue dye and applied on steam-rolled oat groats (0.01% diphacinone) for broadcasting in areas of squirrel activity. The label recommends 4 applications of bait at a rate of 11 kg ha⁻¹ with 48 h between applications. The aim is to provide an uninterrupted supply of bait over a 6-8 d period so that all ground squirrels have the opportunity to find and consume a lethal dose. With growing concern over poisoning of non-target species with anticoagulant baits, Whisson and Salmon (2002) developed a baiting strategy where only 2 applications with 3-5 d between applications are necessary to achieve control. Reducing the amount of bait per application by 71% had no significant effect on ground squirrel mortality rate.

Calciferol (Vitamin D₂) & Cholecalciferol (Vitamin D₃)

Calciferol and cholecalciferol are Vitamin D products and acute rodenticides that the United States Environment Protection Agency registered in the early 1990's for commensal rodent control (Matschke and Andrews 1990). Calciferol is a natural product found in dairy products and fish liver oils (Meehan 1984). Cholecalciferol is an amber crystalline solid practically insoluble in water (Marshall 1984). They promote intestinal absorption of calcium and resorption of bone minerals. This leads to hypercalcaemia, osteocalcaemia, and metastatic calcification of the blood vessels (Meehan 1984).

There are indications that calciferol and cholecalciferol quickly reduce appetite and induces "bait shyness" (Rennison 1974). There is controversy concerning the stability of the ready-to-use baits and concentrates. Pure calciferol decomposes within 2-3 days at room temperature, and in the presence of air and moisture (DeLuca 1970). The toxicity of damp calciferol baits has been found to decrease significantly within a week (Greaves et al. 1974).

Matschke and Andrews (1990) found that, in no-choice laboratory tests, Richardson's ground squirrels accepted cholecalciferol-treated grain baits, and the majority died within 6 days.

Foam

RoCon[®] (Exit[®]) consists of a surfactant with mustard powder which, once mixed with water, produces a foam that can be injected in a burrow system. The animals die from asphyxiation. Proulx (2002a), in a study of a pre-industrial version of the product, concluded that this product had the potential to control >99% of the Richardson's ground squirrels on the basis of visual counts. Proulx (2009a) re-evaluated the performance of this product using capture-recapture data. In spring, RoCon[®] controlled 34-35% of the populations. The product had been mixed with hard water, and it failed to produce abundant foam. In summer, water softener improved the quality of the foam, which controlled 34.4-45.3% of the ground squirrels.

Table 2. Anticoagulant baits used in the field for the control of ground squirrels.

Species	Anticoagulant baits			Reference
	Poison & Carrier	Concentration and application	Control level	
California ground squirrel (<i>Spermophilus beecheyi</i>)	Diphacinone	0.005-0.01%	91-100%*	Kreps and Dixon 1975 Marsh and Howard 1975b
	Diphacinone Chlorophacinone grain	0.01% 0.005%	>70%	Salmon et al. 2007
Columbian ground squirrel (<i>Spermophilus columbianus</i>)	Bromadiolone Chlorophacinone	0.005% 0.005% Broadcasted with a hand-operated mechanical operator	70-100%**	Askam 1985
Richardson's ground squirrels	Bromadiolone Chlorophacinone-chopped cabbage	0.005% 0.005% Broadcasted	31-64%***	O'Brien 1979
	Chlorophacinone-hulless oats	Concentrate 0.7% 2 x 15 g/ burrow opening	Alfalfa - 49.7-63%§	Proulx and Walsh 2007
	Chlorophacinone on hulless oats	Concentrate 0.7% 2 x 15 g/ burrow opening	Spring Grassland - 89.2-100%§ Summer Grassland - 67.2%; alfalfa - 50.8%§	Proulx et al. 2009a
	Chlorophacinone-winter wheat grain	RTU 0.005% 2 x 15 g/ burrow opening	Spring grassland - 71.9-95.1%§ Summer Grassland - 67.2%; alfalfa - 67.2 %§	Proulx et al. 2009a
	Chlorophacinone-on hulless oats with an attractant	Concentrate 0.7% 2 x 15 g/ burrow opening	Spring Grassland - 100% Summer Grassland - 75.4%; alfalfa - 40.3%§	Proulx et al. 2009a
	Chlorophacinone-hulless oats with an attractant	Concentrate 0.7% 1 x 30 g/burrow opening & 1 kg in 40-m-equidistant bait stations in perimeter	Spring Grassland - 100%§ Summer Grassland - 50.8%§	Proulx et al. 2009a
	Chlorophacinone-hulless oats with an attractant	0.7% concentrate 1 kg in 20-m-equidistant bait stations in and around the field	Spring Grassland - 73.1-85.7%§ Summer Grassland - 62.7-76.6%§	Proulx et al. 2009a
	Diphacinone Chlorophacinone-"bait"	0.005% 0.005%	Spring - Alfalfa-grassland 29% on average 84% on average	Johnson-Nistler et al. 2005

*Evaluation method unknown.

** Based on active burrow hole counts.

*** Based on visual counts.

§ Based on capture-recapture data.

Gases

The efficacy of gases to kill ground squirrels is affected by soil porosity and moisture, i.e., dry porous soils allow a greater diffusion of gas (McClellan 1981, Moline and Demarais 1987) and ground squirrels may not receive a lethal dose. For this reason, it is often recommended to use fumigants in spring, when the soil moisture is relatively high (Salmon and Schmidt 1984). It is unlikely that absolute control of the populations can be achieved with gases. Variation in length and complexity of burrow systems, and the animal's position in the burrow during treatment, probably affect survival. Ground squirrels located deep within complex burrow systems may receive only sublethal amounts of phosphine (Fagerstone et al. 1981, Proulx et al. 2009a). All living organisms inhabiting ground squirrel burrow systems may be killed. Therefore, gases must be carefully used in areas inhabited by species at risk such as the burrowing owl (*Athene cunicularia*) and the swift fox (*Vulpes velox*) (Littrell 1990, Proulx and Walsh 2007).

Acrolein

It is an aquatic herbicide under the name Magnicide "H". It is used in the United States as a ground squirrel burrow fumigant. In Canada, it is registered as a microbiocide and herbicide (Pest Management Regulatory Agency 2009). It comes in a liquid form and is dispensed precisely under pressure from a nitrogen tank, by a hose and nozzle gun. Acrolein is a lachrymator with a very pungent smell (UCANR 2008).

The application of acrolein is labour and equipment intensive. Protective clothing (including mask, goggles, safety suit and gloves) must be worn. Acrolein is highly flammable and highly chemically reactive. It requires a restricted use permit. It must be purchased in large quantities, and so may not be cost efficient unless it is used in areas with a severe ground squirrel problem (UCANR 2008). It costs 4 times more than aluminum phosphide (Clark 1994). The product may be phased out by the manufacturer.

Anhydrous ammonia

It is sold as a compressed gas (Gophinator) for the control of ground squirrels. Although no data exists on the effectiveness of anhydrous ammonia, there has been, at best, mixed results with its use (Alberta Agriculture and Rural Development (2001). The cost, utility, practicality and labour are considered serious drawbacks to anhydrous ammonia fumigation.

Aluminum phosphide

Aluminum phosphide tablets function by releasing hydrogen phosphide gas (phosphine, PH_3 through reaction of aluminum phosphide with moisture in the soil and atmosphere) (Salmon and Bentley 1982). Phosphine is toxic to all forms of life. It is colorless, heavier than air with a specific gravity of 1.2, only slightly soluble in water, and has a pungent odour. It is very penetrating and will probably pass through loosely packed soil easily (Salmon and Bentley 1982). The rate of decomposition of tablets varies with temperature and moisture; higher temperature and moisture causes faster decomposition. Assuming a burrow temperature of 18-21°C and relative humidity of 90%, it is estimated that less than 2 days are required for complete liberation of the hydrogen phosphide (Degesh manufacturer's specifications in Salmon and Bentley 1982). The application of aluminum phosphide is faster than that of carbon monoxide cartridges (Salmon and Bentley 1982). Aluminum phosphide tablets are expensive, and can be dangerous to users (Proulx and Walsh 2007). However, Baker (1992) monitored air, clothing and

gloves during the application of tablets by hand and with a mechanical (closed system) applicator. He found that no levels of phosphine exceeded the legal permissible exposure limits. The use of a mechanical applicator resulted in significantly lower phosphine exposure.

Aluminum phosphide appears to be the most advantageous gas to control ground squirrels (Table 3). However, even in the spring, if fields are without vegetation (a sign of poor soil moisture), phosphine escapes and does not kill the majority of ground squirrels (Proulx and Walsh 2007). In fields with vegetation cover, during 2 consecutive years, aluminum phosphide killed > 70% of the ground squirrels (Proulx and Walsh 2007, Proulx et al. 2009a).

Carbon monoxide

Gas cartridges consist of sodium nitrate, charcoal and various sulphur components. These cartridges are lit up and placed as far as possible in to the ground squirrel's burrow. Smoke and toxic gases (mostly carbon monoxide and a small quantity of carbon dioxide) are produced, fill the burrow, and kill the animal by asphyxiation (Zhi and Chang 1986).

Carbon monoxide gas cartridges are expensive, and can be dangerous to users (Zhi and Chang 1986). There is also a dose-effect relationship for the duration of carbon monoxide hypoxia that is influenced by age, sex and body weight (Cameron 1941, Matschke and Fagerstone 1984). According to Ali et al. 1994, carbon monoxide cartridges may be inefficient where ground squirrels have well-established burrow systems.

Rodenator

A calibrated mixture of propane and oxygen is injected in the rodents burrow, and lit up to create an underground shockwave. It is claimed that ground squirrels die from a concussion or injuries due to the collapsing tunnel. This control method has not been scientifically tested. In 2008, the Rodenator was at the origin of an extensive grass fire west of Calgary (D'Aliesio, 2008).

Strychnine

Strychnine is a constituent of the seeds *Strychnos nux-vomica* of India and Indonesia (Brookes 1975). The seeds of this plant have been used to kill dogs (*Canis spp.*), cats (*Felis spp.*), and birds in Europe as early as the 17th century (Gratz 1973).

Strychnine was first registered in Canada in 1928 (PMRA 2005). However, the Saskatchewan Department of Agriculture first gave out instructions for mixing strychnine bait in 1912 (Isern 1988). High concentration (5%) liquid strychnine used to be available to producers. However, in 1993, the Canadian federal government banned the popular 5% strychnine solution (Owen Carter 1993). Today, a special registration program allows for the sale of 2% liquid strychnine (to be mixed with grain to produce freshly-mixed 0.4% baits) and ready-to-use 0.4% strychnine-treated oats.

Table 3. Gases used in the field for the control of ground squirrels.

Species	Gas			Reference
	Type	Concentration and application	Control level - %	
California ground squirrel and the Belding's ground squirrel (<i>Spermophilus beldingi oregonus</i>)	Acrolein	92% acrolein charged with liquid nitrogen, 20-40 ml/burrow opening	90% ^u	Clark 1994
	Aluminum phosphide	2 x 3 gr tablets, (55% aluminum phosphide)/burrow opening	100%*	Salmon and Bentley 1982
		4 x 3gr tablets	100%*	
Richardson's ground squirrel	Aluminum phosphide	1 x 3 g/burrow opening	Field without vegetation 36%** Field with vegetation 71.4%**	Proulx and Walsh 2007***
	Aluminum phosphide	1 x 3 g/burrow opening	Grassland 78.5-85.1%**	Proulx et al. 2009a
	Carbon monoxide	65 g sodium nitrate (65%) and charcoal (35%) cartridges in openings	68%§	Fagerstone et al. 1981
	Carbon monoxide	97 g cartridges in openings	84%§	Matschke and Fagerstone 1984

^uEvaluation method not specified by the author

*Based on visual counts

*Based on capture-recapture data.

***See Proulx et al. (2009a) for corrected performance levels.

§Based on radiotelemetry.

Strychnine is a source of concern for the public, agricultural departments, wildlife biologists, and veterinarians (Carter 1993, Landals 1993, Wamock and Schwarzbach 1995, Snyder-Connet et al. 1999, Simpson 2008, MacDonald Family Animal Rescue 2009). Strychnine exerts its effects almost entirely through the spinal cord. It acts as a stimulant because it blocks the action of the natural inhibitory chemical in the spinal cord known as glycine. Since it acts only on the spinal cord, strychnine will not cause unconsciousness nor will it have any effect on pain perception, since these things involve the brain. The first symptoms of restlessness and twitching are followed by violent convulsions. The animal dies of either respiratory paralysis and suffocation, or from the stress and pain of the convulsions (Livingston 2002).

Poor strychnine performance may be caused by poor bait acceptance (Proulx and Feldstein 1994). Poison bait shyness has also been suggested to explain poor killing efficiency. Because strychnine has a bitter taste and acts rapidly even at sublethal doses, animals can associate the poison bait with their illness and curtail their feeding (Record 1978). Poor control efficacy also result from using strychnine that has been stored for many years. Proulx and Walsh (2007) achieved only 38% control when preparing baits with liquid strychnine that had been kept in storage for 5 years. When using freshly produced strychnine, however, the control efficacy was > 78% (Proulx et al. 2009a). The placement of the strychnine-treated bait does not appear to affect

its effectiveness in controlling Richardson's ground squirrels. Sullins (1982) found equivalent reduction in Richardson's ground squirrel populations when strychnine-treated grain bait was applied on the surface of the ground than when applied in burrows. Application of bait on the surface of the ground is unacceptable, however, because of the higher risk of primary poisoning to seed-eating birds as compared to when bait is applied in burrows (McKinnon 2004). Proulx and Walsh (2007) also showed that strychnine-treated bait rejection was similar between a study plot with holes left open after treatment, and holes covered with dirt after treatment (as per label instructions).

For species such as the Columbian ground squirrel, which does not carry as much food in their cheek pouches (an important site of absorption for strychnine, Merriam 1910) as other species, strychnine grain baits were found ineffective (Record 1978). For the Richardson's ground squirrel, however, Proulx et al.'s (2009a) findings suggest that FM 0.4% strychnine-treated oats have the potential to control >70% of ground squirrels in spring and summer (Table 4). Bourne et al. (2002) suggested that strychnine-treated canary seeds were superior on the basis of visual counts, active burrow hole counts and the collection of carcasses. However, while these evaluation methods allow one to determine population trends after treatment, they are not adequate to assess the true control efficacy of poisons (Proulx and Walsh 2007, Proulx et al. 2009a). Using capture-recapture data, Proulx et al. (2009a) showed that canary seeds were less effective than oats to control adult populations in the spring.

In the laboratory, using animals that had been fasting for 24 h, Matschke et al. (1987) concluded that Richardson's ground squirrels may be effectively controlled at the 0.2% or lower strychnine concentration. In the field, however, tests with 0.2% strychnine-treated baits controlled < 70% of ground squirrels (Table 4). Baits with 0.35-0.4% strychnine have been found to be effective (Table 4), particularly if they are fresh. When using RTU 0.4% strychnine baits, Proulx and Walsh (2007) and Proulx et al. (2009a) achieved < 60% control.

Littrell (1990) believes that strychnine is the worst rodenticide for wildlife because of its toxicity to a variety of species and because of its secondary persistence. Bait rejection at burrow entrances is particularly frequent with strychnine-treated oats and canary seeds during spring and summer (Proulx and Walsh 2007, Proulx et al. 2009a). McKinnon (2002) estimated the amount of wheat found on the surface of the soil at burrow entrances was 4 kernels/burrow. This is sufficient to poison non-target species such as songbirds for which the LD₅₀ is 1-4 kernels. Proulx et al. (2009a) reported a large number of non-target birds and small mammals, particularly horned larks (*Eremophila alpestris*) and deer mice (*Peromyscus maniculatus*). Uresk et al. (1987) reported high losses of horned larks when controlling black-tailed prairie dogs (*Cynomys ludovicianus*) with strychnine baits. Wamock and Schwarzbach (1995) reported strychnine poisoning of dunlin (*Calidris alpina*) and killdeer (*Charadrius vociferous*). Non-target poisoning is aggravated by an improper placement of strychnine baits on surface (a practice still observed today, Proulx, 2008, personal observations) rather than in rodents' burrow openings (Howell and Wishart 1969, Hegdal and Gatz 1977, Wobeser and Blakley 1987). Mendenhall and Pank (1980) reported secondary poisoning of owls. James et al. (1990) observed American crow (*Corvus brachyrhynchos*), black-billed magpie (*Pica pica*), California gull (*Larus californicus*), northern harrier (*Circus cyaneus*), and burrowing owl feeding, or

attempting to feed, on dead ground squirrels poisoned with strychnine. Each year, accidental human poisoning continues to be a problem (Eisemann and Petersen 2002).

Table 4. Strychnine baits used in the field for the control of ground squirrels.

<i>Species</i>	<i>Strychnine baits</i>			<i>Reference</i>
	<i>Carrier</i>	<i>Concentration and application</i>	<i>Control level - %</i>	
Richardson's ground squirrel	Grain	0.35-0.44% By hand at burrow entrances and broadcasted	73-97%*	Record 1978
	Hulless oats	15 g FM 0.4% – old production from 2002 – per burrow opening	38.1%**	Proulx and Walsh 2007***
	Hulless oats	15 g RTU 0.4% per burrow opening	33.3-59.7%**	Proulx and Walsh 2007***
	Hulless oats	15 g RTU 0.4% per burrow opening	Spring - 47.6-53.4%** Summer - 18-26.2%**	Proulx et al. 2009a
	Hulless oats	15 g FM 0.2% per burrow opening	Spring - 48.4-52.3%** Summer - 59-65.8%**	Proulx et al. 2009a
	Hulless oats	15 g FM 0.4% – new product from 2008 – per burrow opening	Spring - 73.1-95.4%** Summer - 75.4%**	Proulx et al. 2009a
	Canary seeds	15 g FM 0.4% per burrow opening	Late summer - 71.7-91.7%*	Bourne et al. 2002
	Canary seeds	15 g FM 0.4% per burrow opening	Spring - 63.9-84.5%** Summer - 83.4-92.2%**	Proulx et al. 2009a

*Based on visual estimates, dead animal counts, and active burrow hole counts.

**Based on capture-recapture data.

***See appendix in Proulx et al. (2009a) for corrected performance levels.

Zinc phosphide

Zinc phosphide is an acute rodenticide in use since the beginning of the 20th century (Schoof 1970). Upon ingestion, zinc phosphide reacts with acids in the gastrointestinal tract and produces phosphine which enters the blood stream. It is a slow acting acute rodenticide and death from asphyxia normally occurs within 24 h after ingestion (Tickes et al. 1982).

Zinc phosphide has a fairly good safety record and is inexpensive. It is toxic to most forms of animal life and no antidote is known (Hood 1972). Uresk et al. (1987) reported high losses of deer souse and eastern cottontail (*Sylvilagus floridanus*). On the other hand, zinc phosphide has a garlic-like odour that is a repellent to man. Yet, human poisoning cases still occur on a yearly basis (Eisemann and Petersen 2002).

Marsh (1987) indicated that results with zinc phosphide are very inconsistent and erratic (25-75%), often for unknown reasons. McKinnon (2004) reported an average control of 36% with 2% zinc phosphide. Marsh (1987) recommended prebaiting, microencapsulation of the active ingredient, improved bait formulations, reducing available alternate food, and better timing of application to improve the efficacy of zinc phosphide.

Table 5. Zinc phosphide baits used in the field for the control of ground squirrels.

<i>Species</i>	<i>Strychnine baits</i>			<i>Reference</i>
	<i>Carrier</i>	<i>Concentration - %</i>	<i>Control level - %</i>	
California ground squirrel	Cabbage	2%	39%*	O'Brien 1978
Richardson's ground squirrel	Steam-rolled oats as prebait and carrier	2% - entrance of burrow systems in May-June	59.5%**	Matschke et al. (1982)
		July-August	95%**	
	Steam-rolled oats as prebait and carrier	2% Broadcasted	85%**	Matschke et al. 1983

*Based on visual counts.

** Based on capture-recapture.

3.1.1.3 Potential Toxicants

Pesticide companies continuously bring forward new toxicants that have been tested with rats (*Rattus norvegicus*) and mice (*Mus musculus*). Many of them have little potential for the control of Richardson's ground squirrels in Canada either because they would not meet animal welfare standards, practical considerations for their application in fields, cost, or considerations relative to control selectivity and efficiency, and environmental contamination. The following toxicants are options that need to be considered when assessing new products for the control of Richardson's ground squirrels.

Racumin Plus

In the last decades, rats developed an increased resistance to anticoagulants in certain areas of the world (MacNicol 1982, Greaves 1986). Racumin Plus is a combination of the anticoagulant coumatetralyl and cholecalciferol. Coumatetralyl is a multi-dose anticoagulant with a highly cumulative effect which acts rapidly (Pospochil and Schnorbach 1994). Fast-acting cholecalciferol may cause bait shyness in higher doses (more than 0.05%). The combination with coumatetralyl allows a reduction of the cholecalciferol concentration to avoid bait shyness. Pospochil and Schnorbach (1994) found that the formulation with optimal rodenticidal efficacy for rats and mice contained 0.04% coumatetralyl and 0.025% cholecalciferol mixed in rolled oats.

Rodetrol

Rodetrol is cellulose from powdered corn cobs that is applied inside buildings to control rats or mice. The mode of action for cellulose from powdered corn cobs is not clear, but it appears to interfere with the digestive system by causing blockages in the intestine and caecum, resulting in dehydration and eventually death. In order to be effective, all other potential food sources must be removed from the treatment location. To date, the product has been tested indoors with commensal rodents. It has not been tested with ground squirrels (PMRA 2007).

Bromadiolone (Contrac)

Contrac is a single-feeding anticoagulant bait containing bromadiolone (see Section 3.1.1.2). It is registered in Canada (http://pr-rp.pmra-arla.gc.ca/pls/portal/PUBLIC_REGISTRY.LBL_ABSTRACT?p_disp_regnum=22232).

Bromethalin (Fastrac)

In the mid-1970s, the search for a novel rodenticide with a mode of action different from anticoagulants led to the identification of a group of compounds classified as diphenylamines (Spaulding and Spanring 1988). This resulted in the production of an acute, very hazardous (Pasquale-Styles et al. 2006) rodenticide called bromethalin. Experiments on the physiological and biochemical mechanisms of action suggests that bromethalin uncouples oxidative phosphorylation (major mechanisms for the production of ATP in the brain) in central nervous system mitochondria (VanLier and Ottosen 1981). In animals, bromethalin is absorbed rapidly by the gastrointestinal tract, and blood concentrations peak within approximately 4 h (VanLier and Cherry 1988). The acute effects of bromethalin are tremors, convulsions, prostration and death, usually within 18 hours following its ingestion (Jackson et al. 1982, VanLier and Cherry 1988). Its LD₅₀ for commensal rodents ranges from 2 to 8 mg/kg (Jackson et al. 1982, Spaulding and Spanring 1988, Dorman et al. 1990). Fastrac (0.01% bromethalin) is registered in Canada (http://pr-rp.pmr-arla.gc.ca/pls/portal/PUBLIC_REGISTRY.LBL_ABSTRACT?p_disp_regnum='27366'&p_regnum=27366) for the control of rats and mice. It kills them in 1-2 days, often within 24 hours. Rodents stop feeding after eating a lethal dose (see: <http://www.discountwildlifesupplies.com/index.html?lang=en-us&target=d73.html>).

3.1.1.4 A comparison of toxicants

Current and potential toxicants' characteristics are presented in Table 6. In some cases, the information was based on work done with species other than ground squirrels. Also, while it is known that some commensal rodents can develop a tolerance to anticoagulants, it is unlikely that such a tolerance exists among ground squirrel species. This does not mean, however, that ground squirrels could not develop a tolerance over time.

3.1.2 Chemosterilants

Marsh and Howard (1970) suggested controlling ground squirrels by utilizing toxicants as selectively as possible for an initial reduction of "hot spots", and broadcasting chemosterilants to keep the populations at an economically tolerable level. However, Alsager and Yaremko's (1972) study of the effects of diethylstilbestrol (DES) and mestranol on Richardson's ground squirrels' reproduction was inconclusive. They found that intramuscular injections of DES caused gonadal atrophy (not necessarily related to reduced gametogenesis). The fall injection of chemosterilants did not inhibit reproduction the following spring. Finally, concentrations greater than 0.5% mestranol reduced bait palatability.

Goulet and Sadleir (1974) showed that female Richardson's ground squirrels that ingested mestranol before or in early pregnancy failed to give birth. They concluded that mestranol was an effective agent to sterilize adult females, although it suppressed fertility for a single breeding season only. A side-effect of the treatment was to reduce total aggression and it was easier for young squirrels to move in established territories. Also, after a first season of treatment, higher immigration and survival of young compensated for the original low birth rate. When mestranol treatments were repeated over 2 seasons, the populations were incapable of compensating for their low densities as the number of births and potential immigrants had been drastically reduced.

Table 6. Characteristics of current, and potential toxicants for the control of Richardson's ground squirrels.

<i>Toxicant</i>	<i>Acceptation by rodents</i>	<i>Causes bait shyness</i>	<i>Rodents could develop tolerance</i>	<i>Safety to user</i>	<i>Non-target poisoning</i>	<i>Secondary poisoning</i>	<i>Potential to control ground squirrels</i>
<i>Current toxicants</i>							
Anticoagulants	High	No	Yes	High	Yes	Yes	High
Calciferol & Cholecalciferol	High	Yes	No	High	Yes	No	Unknown – probably low
Foam	n/a	No	No	High	Yes	No	Low
Gases	n/a	No	No	Low	Yes	No	High
Strychnine	Medium	Yes	No	Low	Yes	Yes	High
Zinc phosphide	Low	Possibly	No	Medium	Yes	No	Inconsistent
<i>Potential toxicants</i>							
Racumin Plus	Unknown	Unknown	Unknown	High	Yes	Yes	Unknown
Rodetrol	Low in presence of vegetation	Unlikely	No	High	Yes	No	Unknown
Bromadiolone	High	No	Yes	High	Yes	Yes	High
Bromethalin	Likely	Possibly	No	Low	Yes	No	Probably high

n/a – not applicable

The National Wildlife Research scientists have successfully tested a single-injection, GnRH (gonadotropin-releasing hormone), immunocontraceptive vaccine (called GonaCon™) on free-ranging California ground squirrels (Miller 2004). In a 2-year study, 229 male and female squirrels were trapped and injected with a single dose of GnRH preparation. This resulted in a significant reduction in lactation in females through the 2-year period, as well as reduction in sexually-active males (Nash et al. 2004). However, there is still not a chemosterilant that has been approved for the control of ground squirrels (UCANR 2008).

3.1.3 Repellents

In coniferous forests, Kverno (1964) found that chemical repellents such as endrin were not especially effective against ground squirrels. Electromagnetic devices, sound, ultrasound, and visual repellents are ineffective (Sprock et al. 1967, Stewart 1974, Smith 1979, Marsh 1994).

3.2 MECHANICAL CONTROL

3.2.1 Shooting

Shooting may be used to remove limited numbers of invading ground squirrels or as a clean-up technique supplementing other control methods (Salmon and Schmidt 1984). It is considered a labour-intensive control technique and, although it is not recommended for removing large numbers of squirrels (Storer 1949), it has not been subjected to a thorough evaluation. A major advantage of this control technique would be its low cost, since labour and equipment are supplied on a voluntary basis (Knowles 1987). Shooting a few squirrels often results in the remaining animals becoming extremely wary and difficult to shoot (Dixon 1925). Knowles (1987), in an evaluation of the effectiveness of a black-tailed prairie dog control program, recommended that shooting be carried out during spring while females are pregnant or lactating.

Pauli and Buskirk (2007) pointed out that, because recreational shooters mostly use expanding bullets and rarely remove or bury carcasses, the amount of lead in shot animals is potentially sufficient to acutely poison scavengers and predators. Knopper et al. (2006) pointed out that scavenging Swainson's (*Buteo swainsonii*) and ferruginous (*Buteo regalis*) hawks could ingest an appreciable amount of lead that could prove fatal. The hazard could be avoided with the collection and disposal of shot carcasses and with the use of steel, tungsten-nylon or polymer would eliminate the risk of lead poisoning.

3.2.2 Trapping

Trapping is used to remove ground squirrels from localized areas or where other techniques are either ineffective or undesirable. It is also used to remove individuals that escaped control from toxicants. It is usually considered labour-intensive (Salmon and Schmidt 1984). Although many trapping devices are sold on the market for the capture of ground squirrel-size rodents, little information exists on the efficacy and humaneness. Proulx and Feldstein (1994) considered that there was a need for improved, more efficient, trapping devices.

3.2.2.1 Killing traps

Edge and Olson-Edge (1990) assessed the relative effectiveness of the Conibear 110 and a pocket gopher-type killing box to remove Columbian ground squirrels. They estimated control at 40%. Marsh (1994) preferred the Conibear 110 over other traps because it can be placed directly over the burrow opening and, therefore, does not require bait to entice the squirrel into the trap.

3.2.2.2 Live-holding traps

Edge and Olson-Edge (1990) reported a 40% control level with the 15 x 15 x 48 cm Tomahawk live-trap. Matschke et al. (1982) captured Richardson's ground squirrels using Tomahawk-type cage traps baited with wheat and sorghum. Proulx and Walsh (2007) used peanut butter on bread. Wobeser and Leighton (1979) recommended the use of home-made wire mesh traps equipped with a "push-up-self-return" door. Focal setting, i.e., the trap is set in burrow openings where ground squirrels have been seen to enter, is more effective.

3.3 CULTURAL CONTROL

3.3.1 Disking or plowing

Repeated disking or plowing of California ground squirrel-infested areas will incite animals to move to the margins of the fields along fence rows, ditches or road right-of-ways (Marsh 1994). Also, eliminating vegetation as close to fence lines as possible will reduce ground squirrel numbers (Fitzgerald and Marsh 1986).

3.3.2 Tall vegetation

Ground squirrels establish their burrow systems in fields with shorter vegetation; they prefer sites with good visibility and short vegetation (Yensen and Sherman 2003). Also, Proulx and Mackenzie (this report, Sections 5.3 and 5.4) reported lower densities of animals and burrow holes in areas with ≥ 15 cm-high vegetation compared to areas with <15 cm-high vegetation. However, tall vegetation will not cause permanent reduction of the populations (Fitzgerald and

Marsh 1986), and it is not a limiting factor as long as there is an unlimited food supply (Fitch 1948) and raised ground for protection from flooding (Phillips 1936).

3.3.2 Burrow destruction

Salmon et al. (1987) found that surface destruction (30 cm) of California ground squirrel burrow openings did not dramatically affect the rate or extent of recolonization. However, Gilson and Salmon (1990) found that ripping up the entrances of the burrow systems with a tractor-drawn ripper driven back and forth across the colony was beneficial. Ripping should be at least 45 cm deep, but the deeper the better.

3.3.3 Exclusion

Fencing is not considered a practical solution because ground squirrels are good diggers and excellent climbers. Some innovative electrified fences have provided partial relief by protecting small plots for a growing season (Marsh 1994).

3.3.4 Visual barriers

The installation of temporary or permanent opaque fencing (i.e., shadecloth-covered fencing) can deter ground squirrels dispersal movements by limiting the animals' ability to view their environment and check for predators. This technique has been a successful and cost-effective component of the ground squirrel integrated pest management in the City of Palo Alto, California (Proulx 2008).

3.4 NATURAL CONTROL

Populations of natural predators can be enhanced locally in order to increase mortality in small rodent populations. This can be done by offering shelter, nest sites, perches, etc. (Erlinge 1975, Hall et al. 1981, Askham 1990).

3.4.1 Mammalian Predators

3.4.1.1 Badger

Proulx et al. (2009b) found a significant relationship between the density of badger and Richardson's ground squirrel holes/ha in fall. It is worthwhile to mention that burrowing owls appear to prefer nesting in areas of high burrow densities and select badger-sized burrows for nesting and roosting (Poulin et al. 2005).

Badgers are known to feed on fossorial mammals (Lindzey 2003). Messick and Hornocker (1981), Snead and Herickson (1942) and Proulx et al. (2009b) found that remains of ground squirrel species was higher in spring and summer. In late summer and fall, the food habits became more diversified, including several small mammals, insects and vegetation. Proulx et al. (2009b) hypothesized that badgers may have difficulty in finding hibernating ground squirrels, and suggested that it may have a significant impact on ground squirrel populations in spring and summer only.

3.4.1.2 Long-tailed weasel

Long-tailed weasels feed almost exclusively on small rodents, but their impact on Richardson's ground squirrels is poorly known (see review by Svendsen 2003). In the absence of data, Michener (*in* Bernard et al. 2004) estimated that weasels could reduce juvenile Richardson's ground squirrel numbers by up to 50% in one season through infant predation. On the basis of capture-recapture of juvenile populations in fields with and without long-tailed weasel latrines, Proulx et al. (2009b) estimated that weasels controlled 44% of juvenile ground squirrels in grasslands. They also found that, from April to July, Richardson's ground squirrels were the predominant prey of weasels, being found in 85% of scats. In August-September, however, small mammals and insects were the most frequent food items present in scats.

3.4.1.3 Coyote

Coyotes are opportunistic, generalist predators and eat a variety of food items in relation to changes in availability (Bekoff and Gese 2003). Studies have shown pronounced seasonal variation in coyote diets related to availability of foods (Gipson and Sealander 1976, Litvaitis and Shaw 1980, MacCracken and Hansen 1982, Van Vuren and Thompson 1982, Andelt et al. 1987, Reichel 1991). Little is known about the impact of coyotes on ground squirrel populations. Many studies reported ground squirrel remains in < 4% of scats in spring and summer (MacCracken 1981, 1982, Ortega 1987). Proulx et al. (2009b) were the first to investigate coyote food habits in areas with exceptionally high population densities of Richardson's ground squirrels. They found Richardson's ground squirrel remains in $\geq 50\%$ of scats from April to July. However, small mammal remains were as important as those of ground squirrels in frequency and volume during the same period. In fall, small mammals and ungulates were predominant in the scats. Coyotes started to feed more on insects (particularly grasshoppers) starting in mid-summer. Proulx et al.'s (2009b) findings in late summer and fall were similar to those of other studies (Murie 1951, Litvaitis and Shaw 1980, Ortega 1987, Reichel 1991, Kuiken et al. 2003, Cepek 2004). Coyotes also feed on badgers in summer and fall (Rathbun et al. 1980, Proulx et al. 2009b).

3.4.1.4 Foxes

Red and swift foxes are opportunistic foragers consuming a variety of foods, including ground squirrels (Cypher 2003). Latham (1952) suggested that red foxes would kill weasels at every opportunity even though they do not find them particularly palatable.

3.4.2 Avian Predators

According to Hall et al. (1981) and Reinert (1984), perches for hunting, resting, and feeding would be important habitat modifications that would bring raptors to feed more on rodents. Askam (1990) installed artificial perches and nest boxes in orchards to attract raptors to reduce vole populations. While birds could be attracted under some conditions, vole populations were not affected. Askam (1990) hypothesized that human habitation and activity may play an important role in the success or failure of attracting birds to a specific site.

With the "industrialization of agriculture", shelterbelts have been bulldozed and large treeless monocultures have been established (Houston and Schmutz 1999), thus reducing the abundance of nesting sites. A greater presence of raptors in an area may result from establishing artificial nests (Schmutz et al. 1984). However, increasing predator numbers in an area is problematic

because most vertebrate predators are territorial, and all territories may already be filled (Lored-Prendeville et al. 1994). Using nearest-neighbour tests, Rothfels and Lein (1983) found regular patterns of nest dispersion for sympatric populations of red-tailed and Swainson's hawks. Also, they suggested that intraspecific and interspecific territoriality explained the pattern of distribution of the nests.

3.4.2.1 Great horned owl

Ground squirrels are frequently reported to form a minor component (< 5%) of the diet of great horned owls (*Bubo virginianus*) (Bird 1929, Hamerstrom and Mattson 1939, Errington et al. 1940, Alcorn 1942, Fitch 1947, Orians and Kuhlman 1956, Seidensticker 1968, Maser et al. 1970, McInville and Keith 1974, Gilmer et al. 1983, Knight and Jackman 1984, Zimmerman et al. 1996, Michener 2001).

3.4.2.2 Ferruginous hawk

Schmutz and Hungle (1989) found that the breeding density and fledging success of the ferruginous hawk, a food specialist, were consistently correlated with Richardsons' ground squirrel abundance. Lokemoen and Duebbert (1976) reported the presence of Richardson's ground squirrel remains in 96% of regurgitation pellets. During the nestling period, ground squirrels averaged 89% of the total prey items for ferruginous hawks studied by Schmutz et al. (1980). Gilmer and Stewart (1983) found that Richardsons' ground squirrels represented 55-75% of prey species at occupied nests. Schmutz and Hungle (1989) also found that ground squirrel carcasses were the sole prey found in ferruginous hawk nests.

3.4.2.3 Swainson's hawk

The Richardson's ground squirrel represented 82% of prey items on Swainson's nests studied by Schmutz and Hungle (1989). However, ground squirrels are at the limit at the upper limit of prey that this medium-sized hawk is able to subdue consistently. The size constraint probably accounts for the small number of adult squirrels in the Swainson's hawk's diet (when compared to the ferruginous hawk diet), and a greater abundance of voles. Schmutz et al (2001) reported populations and productivity declines that coincided with a decline in Richardson's ground squirrel numbers.

3.4.2.4 Red-tailed hawk

Luttich et al. (1970) found that Richardson's ground squirrels dominated the red-tailed hawk diet. On average, their remains corresponded to 18% of leftovers found at nests, and they represented 32% of the total biomass of prey taken by the raptors. Individual nesting pairs of red-tails took between 22% and 60% of various ground squirrel populations. The calculated impact of red-tail predation upon ground squirrels was greatest on the adult cohort; between 52% and 93% of the adults in 2 populations were estimated to have been taken (Luttich et al. 1970).

3.4.2.4 Prairie Falcon

Prairie falcons (*Falco mexicanus*) prey primarily on ground squirrels, secondarily on other small mammals and birds, and occasionally on lizards and insects (Salt and Salt 1976, MacLaren et al. 1988, Steenhof and Kochert 1988, Hunt 1993, Steenhof 1998). In southwestern Wyoming, the most common prey species was Richardson's ground squirrel, with white-tailed prairie dogs (*Cynomys leucurus*), birds, and rabbits making up the remainder (MacLaren et al. 1988). In southern Alberta, 68% and 27% of 250 prey deliveries were ground squirrels and birds, respectively (Hunt 1993). Richardson's ground squirrel, western meadowlark (*Sturnella*

neglecta), horned lark, and European starling (*Sturnus vulgaris*) were the most common species found in prey remains. In northern California, falcons foraged primarily on Belding's ground squirrels (Haak 1982). Hunt (1993) found that diet assessment studies using pellets and prey remains at nest sites underestimated the importance of ground squirrels as prey items because prairie falcons consume some squirrels away from the nest.

3.4.3 Reptilian Predators

3.4.3.1 Rattlesnake

The rattlesnake (*Crotalus viridis*) is the most important snake predator of ground squirrels (Hennessy and Owings 1978). It feeds mainly on ground squirrel pups (Swaisgood et al. 1999).

3.4.3.2 Gopher snake

The gopher snake (*Pituophis catenifer*) is the second most important snake predator (Hennessy and Owings 1978). They capture their prey by actively searching underground tunnel systems, or seizing them while they rest at night (Rodríguez-Robles 2002).

3.4.4 Parasites

Michener (1993) reported that up to 10% of male Richardson's ground squirrels were infested with a sarcophagid fly, *Neobellieria citellivora*. Unfortunately, this parasite has also been known to attack humans, so its usefulness as a planned pest control activity (release of laboratory-reared individuals) is limited (Bernard et al. 2004).

4.0 MAIL SURVEYS

Thirty out of 165 mail surveys were returned: 12 from the Brown, 11 from the Dark Brown, 4 from the Black, and 6 from the Gray soil zones. Only 7 (1 in Dark Brown and 6 in the Gray) reported an absence of Richardson's ground squirrels.

4.1 AVERAGE PERCENTAGES OF INFESTATION IN PASTURES, HAYFIELDS AND CROPS

Richardson's ground squirrels were reported in pastures, pure or mixed alfalfa, crested wheat, wheat, barley, oats, fall rye, triticale, canola, pea, lentil, and flax. Farmers estimated that levels of infestation in any of these fields and crops ranged, on average, from 4.7 to 39.4% (Figure 3). There was no significant difference between average percentages of infestation by Richardson's ground squirrels ($F_{7,66} = 1.19, P > 0.05$).

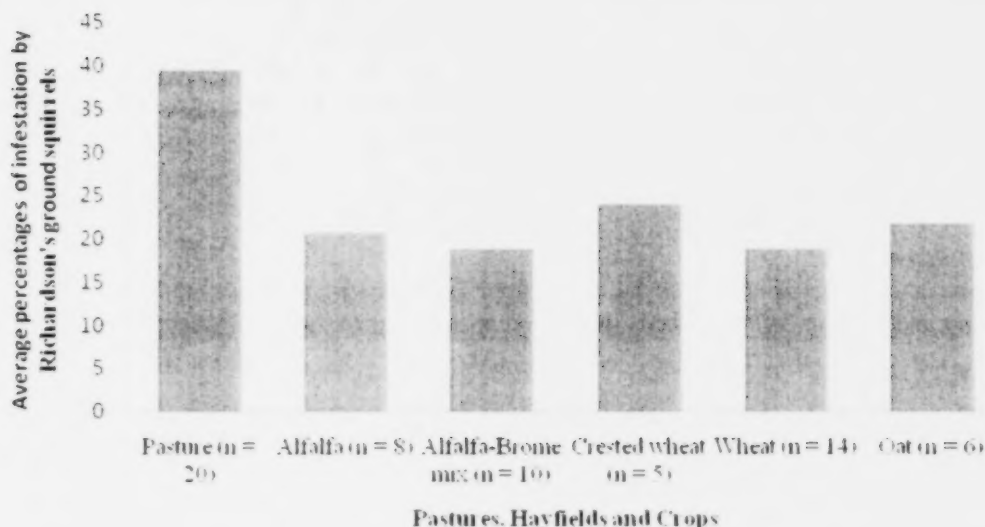


Figure 3. Average percentages of infestation by Richardson's ground squirrels in pastures, hayfields, and crops.

Twenty respondents reported Richardson's ground squirrel infestations in their pastures: 8 in Brown, 8 in Dark Brown, and 4 in Black soil zones. The estimated average percentages of infestation ranged from 30 to 43%. There was no significant difference in the estimated levels of infestation from one soil zone to the other ($F_{2,17} = 0.48$, $P > 0.05$).

The majority of respondents (85.7%) believed that the Richardson's ground squirrel problem increased in their area over the last 5 years.

4.2 LOSSES

Respondents reported average losses of \$1100 in equipment ($n = 10$), \$ 761 in forage ($n = 9$), \$1225 in crops ($n = 8$), and \$1550 in livestock ($n = 4$).

4.3 CONTROL METHODS

The majority (95.7%) of respondents control Richardson's ground squirrels. The most commonly used control method is shooting, followed in order of decreasing importance by FM 0.4% strychnine on grain, RTU 0.4% strychnine on oats, Rozol[®], Phostoxin[®], and trapping (Figure 4). Seventeen (77.3%) of the 22 respondents shoot and poison Richardson's ground squirrels. Only 5 (22.7%) of the 22 respondents use shooting as their only control method.

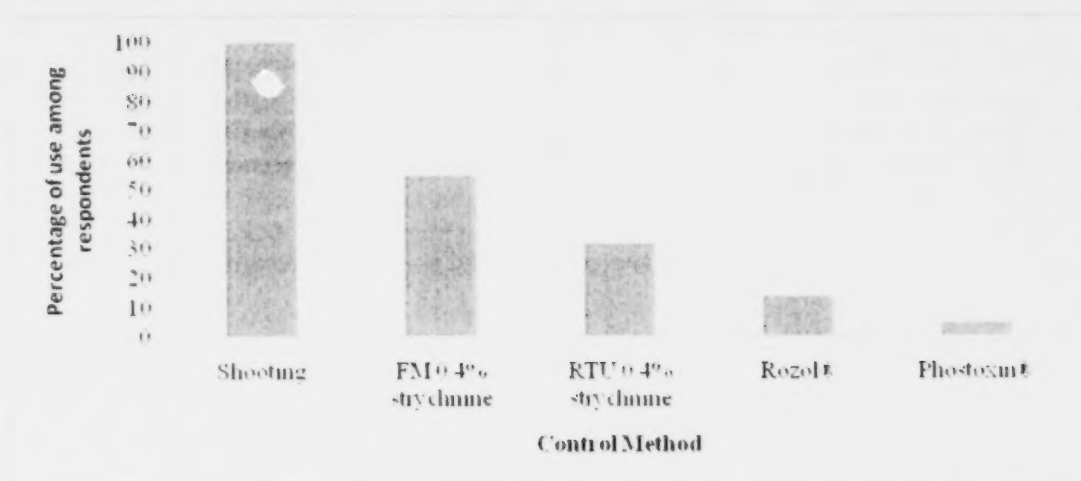


Figure 4. Percentage of use of various control methods by 22 respondents.

The majority (66.7%) of respondents using FM 0.4% strychnine considered that it was a good control method. On the other hand, the majority (57.1%) of those using RTU 0.4% strychnine felt that it was not effective. Only 3 respondents used Rozol®; 1 considered it to be good, and 2 did not know how well it worked. Only 1 respondent used Phostoxin®, and it was with satisfaction. Thirteen producers indicated which control method was the best for the control of Richardson's ground squirrels: 8 (61.5%) preferred shooting, 3 (23.1%) strychnine, and 1 (7.7%) Rozol®. Seven (58.3%) out of 12 respondents were satisfied with their control method.

Considering that 1 day of control equals 8 hours, 18 respondents estimated that they spent, on average, 42.7 hours (5.3 d)/year controlling ground squirrels. All respondents ($n = 16$) judged spring to be the best time of year to control Richardson's ground squirrels. Only 6 (35.3%) out of 17 respondents collected carcasses after poisoning.

Farmers attached comments to their answers. The most frequent comments were requests for:

- stronger poisons.
- unlimited amounts of poisons.
- The return of the old strychnine which is believed to be more potent.

One respondent pointed out that Phostoxin® killed snakes. Two other respondents indicated their concerns with secondary poisoning of pets and badgers.

4.4 PREDATION

Twenty-four producers responded to questions related to badger, coyote, red fox, long-tailed weasel and birds of prey. Independently of the predator, the majority (>80%) of 24 respondents considered that these predators played an important role in the control of Richardson's ground squirrels.

When asked which predator was the best, the majority (52.6%) of 19 respondents believed that birds of prey were the best, followed in order of decreasing importance by coyote (36.8%), red fox (26.3%), and badger and long-tailed weasel (21% each)². Interestingly, when asked which predator was the least efficient, most answers suggested that the badger (45.4% of responses) and birds of prey (27.3%) were the least efficient. Only 9% of the respondents considered that coyote, long-tailed weasel and red fox were inefficient.

Sixteen out of 17 respondents believed that predators could not control Richardson's ground squirrel populations.

5.0 FIELD INVESTIGATIONS

5.1 VISUAL COUNTS vs. SOIL ZONES

The average numbers of Richardson's ground squirrels/0.49 ha, when pooling together all the study plots of a same soil zone, differed significantly ($F_{3,32} = 4.02$, $P < 0.05$) among soil zones. Similar ($P > 0.05$) average numbers of animals were recorded during visual counts in Brown ($\bar{x} = 6.6$ animals; standard deviation = 5.6 animals) and Black ($\bar{x} = 3.1 \pm 2$ animals) Soil Zones. However, the average number of ground squirrels/0.49 ha in the Brown soil zone was significantly ($P < 0.05$) higher than those of the Gray ($\bar{x} = 2.1 \pm 3.2$ animals) and Dark Brown ($\bar{x} = 1.4 \pm 1$ animals) soil zones. There was no significant difference ($P > 0.05$) between the average numbers of ground squirrels/0.49 ha in the Black, Gray and Dark Brown Soil Zones.

The Brown Soil Zone appeared to have, on average, more ground squirrels/0.49 ha when pooling together the study plots of all the regions. When the study plots of a same region of a soil zone were used individually in a comparison of mean number of ground squirrels/0.49 ha, there was also a significant difference among study plots of different soil zones ($F_{11,24} = 42.2$, $P < 0.0005$). However, only the study plot of the central region of the Brown Soil Zone has a significantly greater ($P < 0.05$) number of ground squirrels/0.49 ha than any other study plot (Figure 5). Study plots with relatively higher number of ground squirrels/0.49 ha were also found in the eastern regions of the Gray and Black Soil Zones (Figure 5).

The larger number of ground squirrels/study plot did not appear to be limited to some soil zones in particular, even though the highest numbers were reported in the central region of the Brown Soil Zone, and the lowest in the central and western regions of the Gray Soil Zone.

² The sum of the percentages exceeds 100% because some respondents listed more than one species as best predator.

Average number of Richardson's ground squirrels/0.49 ha	Soil Zone & Study Plot
13.7	Brown central
6.3	Gray east
5.0	Black east
4.3	Brown east
2.3	Black west
	Dark Brown east
2.0	Black central
1.7	Brown west
	Dark Brown central
0.3	Dark Brown west
0.0	Gray central and west

Figure 5. Average numbers of Richardson's ground squirrels/0.49 ha recorded during visual counts in study plots of different soil zones, May-June 2008. Study plots found within a same group had ground squirrel densities that were not significantly ($P > 0.05$) different from each other.

5.2 BURROW HOLE COUNTS vs. SOIL ZONES

The average numbers of Richardson's ground squirrels burrow holes/280 m of transect, when pooling together all the study plots of a same soil zone, differed significantly ($F_{3,32} = 3.3$, $P < 0.05$) among soil zones. The number of holes was significantly ($P < 0.05$) greater in the Brown Soil Zone ($\bar{x} = 30.4 \pm 23.8$ holes) than in the Gray Soil Zone ($\bar{x} = 10.7 \pm 15.2$ holes). However, the number of holes/280 m of transect varied considerably among study plots, and there were no differences ($P > 0.05$) between the number of holes of Brown and Dark Brown ($\bar{x} = 12.1 \pm 5$ holes), and between Black ($\bar{x} = 16.7 \pm 8$ holes) and Gray soil zones.

The Brown Soil Zone appeared to have, on average, more ground squirrel holes/280 m of transect when pooling together the study plots. When the study plots of a same region of a soil zone were used individually in a comparison of mean number of holes/280 m of transect, there was also a significant difference among study plots of different soil zones ($F_{11,24} = 9.0$, $P < 0.001$). However, only the study plot of the central region of the Brown soil zone had a significantly greater ($P < 0.05$) number of ground squirrels/0.49 ha than any other study plot (Figure 3). There was also a significant difference ($P < 0.05$) between the eastern and western

regions of the Gray Soil Zones (Figure 6). All other study plots had a similar ($P > 0.05$) number of ground squirrel holes (Figure 6).

There were many similarities in the order of study plots based either on visual counts or burrow holes (Figures 5 and 6). As was the case with visual counts, the larger number of ground squirrel holes/280 m of transect was not entirely explained on the basis of soil only, even though the highest numbers were found in the central region of the Brown Soil Zone, and the lowest in the Gray central and west regions.

5.3 VISUAL COUNTS vs. VEGETATION HEIGHT

Within a same rural municipality, 2 study plots (located in two different pastures) could have different vegetation heights. In order to better understand counts of ground squirrels and burrow holes, study plots of a same rural municipality were not pooled together. Seven study plots had a vegetation height ≥ 15 cm: 2 in rural municipality no. 290, 2 in no. 111, 2 in no. 316, and 1 in no. 405. All other study plots had a vegetation height < 15 cm. The average number of Richardson's ground squirrels/study plot with vegetation ≥ 15 cm high ($\bar{x} = 1.1 \pm 1.1$ animals) was significantly ($t = 3.11$, df: 36, $P < 0.005$) smaller than in study plots with < 15 cm vegetation ($\bar{x} = 3.8 \pm 4.1$ animals).

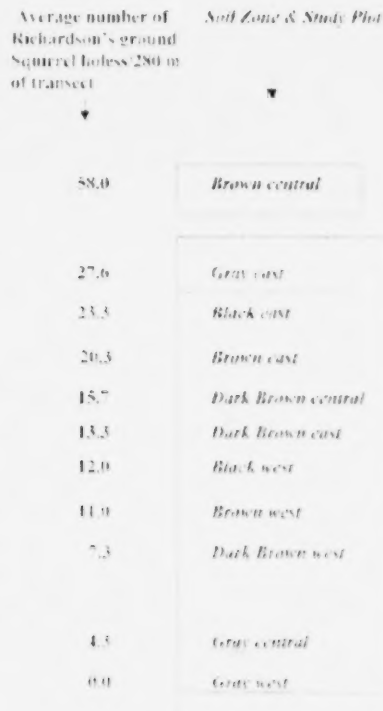


Figure 6. Average numbers of Richardson's ground squirrel holes/280 m of transect in study plots of different soil zones, May-June 2008. Study plots found within a same group had ground squirrel hole densities that were not significantly ($P > 0.05$) different from each other.

5.4 BURROW HOLE COUNTS vs. VEGETATION HEIGHT

The average number of ground squirrel holes/280 m of transect in study plots with vegetation ≥ 15 cm high ($\bar{x} = 9.1 \pm 6.7$ holes) was significantly ($t = 2.36$, df: 39, $P < 0.05$) smaller than in study plots with < 15 cm vegetation ($\bar{x} = 18.9 \pm 17.7$ holes).

6.0 DISCUSSION

An ideal toxicant should be species-specific, palatable, painless, non-cumulative, safe for humans and the environment, capable of rapid decomposition into harmless products, counteracted by an antidote, and economical (Hoffer et al. 1969, Peardon 1974). Furthermore, it should significantly reduce the size of populations. More ground squirrels are born each year than will survive, and removing a surplus of animals that would die anyway has very little impact on populations as a whole (Fitch 1948, Storer 1949, Dana 1962). A toxicant should therefore consistently control at least 70% of populations in order to be considered effective (Barnes 1973, Capp 1976, Fagerstone et al. 1981, Proulx 2002b). No toxicant meets all the characteristics listed above, but a few of them are known to control at least 70% of ground squirrel populations: strychnine, anticoagulants, and gases. In spite of the poor return of questionnaires, mail surveys suggest that producers do not take full advantage of all available, effective toxicants. Strychnine has been, and continues to be, the most popular toxicant used for the control of ground squirrels. However, knowing that this toxicant may kill non-target species, predators and scavengers, and that most producers do not collect carcasses after treatment, the continued use of this toxicant will require a change in its application in order to specifically control ground squirrels. Also, producers will have to spend more than 5 days per year to significantly control populations at landscape level. Since it is known that toxicants work better in spring, producers should focus more on the control of the breeders rather than individuals of all age. Because of the annual variation in environmental conditions and in farming activities, in order to consistently control ground squirrels in an effective manner, producers should use more than one control method. For example, Phostoxin[®] could be used to kill the majority of ground squirrels, and the remaining animals could be removed by placing strychnine or anticoagulants in active burrow systems. Traps could be used to remove small concentrations of animals. The use of several control methods in the spring during a 2-3 week period would likely result in a control program that would be satisfactory to producers.

In this review, we have identified potential toxicants for ground squirrels. However, the search for alternatives is not simple. The acute effect of a toxicant may not be apparent under a certain threshold (Sandusky and Meyers 1985). Also, the control obtained with one rodent species may not be replicable with another species. In the short-term, a solution for the control of ground squirrels should focus on developing better ways to use already registered toxicants rather than seeking unregistered products that require toxicity assessments and the development of proper application protocols. Also, it is unlikely that chemosterilants will become available in the short-term, in spite of USDA's extensive research efforts.

In the long term, the effective management of Richardson's ground squirrel populations should integrate chemical, mechanical, cultural and natural control methods. For example, keeping tall grasses creates environmental conditions that are less favourable to ground squirrels, but

attractive to predators such as weasels. Interspersing pasture and grasslands with less attractive grounds could impact on ground squirrel dispersal and contain populations to specific areas where control methods could be effectively used.

Mail surveys suggest that, while producers admit that predators play an important role in the control of ground squirrels, they may not have a good understanding of their impact on ground squirrel populations. More studies such as those of Luttich et al. (1970), Schmutz et al. (1980), and Proulx et al. (2009b) are necessary to quantify the impact of predation on ground squirrel populations.

The Richardson's ground squirrel problem has been reported in most agricultural regions of the province. However, it is worst in some regions than in others. As pointed out by Saskatchewan Agriculture and Food (2001), using soil zones to explain the distribution of ground squirrels is somewhat imprecise because "leakage" occurs between zones in those rural municipalities that overlap more than one soil zone. At first sight, it appears that there is a larger ground squirrel infestation in the Brown soil zone. However, some of the study plots of the Black and Gray soil zones had very high densities of ground squirrels. Obviously, higher population densities cannot be explained solely on the basis of soils. Many factors may explain higher infestations of ground squirrels. Vegetation height may be one of them; this would be consistent with what is known about the biology of the species (Yensen and Sherman 2003). It was more difficult to detect ground squirrels in >15 cm-high grass, but burrow hole counts ascertained the conclusion drawn from visual counts, i.e., Richardson's ground squirrels were less abundant in taller grass. Farming practices certainly have an impact on ground squirrel population densities. For example, over-grazing creates ideal conditions for this rodent. More work will be required on the ecology of Richardson's ground squirrels to understand factors that impact on their distribution and abundance.

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